made at flight times of $\sim 10^{-8}$ sec from the target yield the same lifetime, within statistical errors, for the $K_{\pi 2}$, $K_{\mu 2}$, and τ mesons.[2,4] These facts, together with the fact that the tau should not decay into two pions,[5] suggest either that there is a single kind of K-meson with lifetime $\sim 10^{-8}$ sec which decays to L-mesons and has a significant branching ratio for gamma decay to a slightly lighter K-meson of shorter lifetime,[6] or that there are two or more kinds of K-mesons with lifetimes $\sim 10^{-8}$ sec but such that the ratio of the number decaying into 3 pions to the sum of the number decaying into 2 pions and $(\mu+\nu)$ is fairly constant. The agreement between our results and those at Berkeley on the relative frequencies of the K-mesons is very striking and taken together with the well-known similarities of lifetimes and masses, probably is indicative of some close relationship between the various K-mesons.[7]

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Heavy-Meson Decays and the Selection Rule $|\Delta I| \leqslant 1/2$

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THE validity of the selection rules,[1]

$$\Delta I_z = 0 \text{ for fast transitions,}$$

$$\Delta I_z = \pm\tfrac{1}{2} \text{ for slow transitions,}$$

is well established in the domain of hyperon and heavy-meson physics. Whether there exists an independent selection rule for the *total* isotopic spin I, *viz.*,

$$\begin{aligned} &\Delta I = 0 \text{ for fast transitions,} \\ &\Delta I = \pm\tfrac{1}{2} \text{ for slow transitions,} \end{aligned} \quad (1)$$

is still debatable. We want to point out that various features of the θ and τ meson decays may be interpreted as favoring the rule (1).

Takeda[2] has already shown that the branching ratio R of the θ^0, decaying into $\pi^0+\pi^0$ or $\pi^++\pi^-$ respectively, should be $\frac{1}{2}$ or 0, for even or odd parity of the θ, if (1) is valid. The explanation is simply that, for a θ of isotopic spin $\frac{1}{2}$, the final two-pion states cannot have $I=2$, according to (1). Then, for a θ of even [odd] parity, only $I=0$ [1] is possible; therefore the θ^0 decays as though it were a particle of isotopic spin 0 [1]. This leads immediately to Takeda's R-values.

With regard to the θ^+ which decays into $\pi^++\pi^0$, we observe that, because of the charge $+1$, the final states can only be $I=1$ or 2, the latter value being forbidden by (1). It follows that the decay rates of θ^+ and θ^0 should be roughly equal if the θ parity is odd [$I=1$], whereas an even θ^+ can disintegrate only in violation of the rule (1). The fact that the lifetime of θ^+ is about 100 times that of θ^0 may be cited as evidence in favor of the second alternative, *viz.*, even parity of the θ, and validity of (1).

A stronger argument results from the study of the τ disintegrations:

$$\tau^+ \rightarrow \begin{cases} 2\pi^+ + \pi^- & (\text{“}\tau\text{ decay”}) \\ 2\pi^0 + \pi^+ & (\text{“}\tau'\text{ decay”}). \end{cases}$$

The branching ratio τ/τ' has been observed to be as large as 4 (average values 4.1 and 4.6 are quoted in the literature[3]). Dalitz[4] has shown that, if the final three-pion state is an eigenstate of I, the branching ratio τ/τ' is $\frac{1}{4}$ for $I=3$, and 1 for $I=2$, whereas

$$1 \leqslant \tau/\tau' \leqslant 4 \quad \text{for } I=1. \quad (2)$$

Thus, the only single I value compatible with the observations is $I=1$. This may either mean that the τ meson has isotopic spin 1 and decays with isotopic spin conservation[4]; but this interpretation would reopen the question why the lifetime of the τ is so long. It is much more natural today to assume that the τ has isotopic spin $\frac{1}{2}$ and that the selection rule (1) is effective, leading to the same limitation for the branching ratio, *viz.* (2).

We observe further that the upper limit 4 for $\tau/\tau'[I=1]$ is obtained only if the state function of the three pions has a particularly simple symmetry property: it has the form $u(\mathbf{p}_1\mathbf{p}_2\mathbf{p}_3)\chi(i_{1z}i_{2z}i_{3z})$ where each factor is totally symmetric in the three particles, namely u with respect to the three momentum vectors, and χ with respect to the three charge numbers. Specifically:

$$\chi = (15)^{-\frac{1}{2}}\{2[(\bar{1}11)+(1\bar{1}1)+(11\bar{1})] - [(100)+(010)+(001)]\}$$

(writing $\bar{1}$ for -1).

It is clear that with mixtures of eigenfunctions of various I-values arbitrary τ/τ' values can be obtained. However, if the experimental value 4 is confirmed, the most plausible explanation would be that the final pion state is a pure $I=1$ state of the special form $u\chi$. Besides supporting the selection rule (1), this would indicate that the interaction responsible for the τ decay is symmetric in the momenta, or coordinates, of the three pions. This implies no restriction for the spin and parity of the τ meson. (It may be mentioned, though, that for a τ of type 1^+ the simplest interaction gives $u=0$ because of momentum conservation,[5] but by inserting suitable relativistic invariants as factors, nonvanishing symmetric functions u can be constructed even in this case. Particularly simple functions can be set up if the τ is 0^-, or 3^+.[6])

As a consequence of the symmetry of u, pions of all charges must have the same energy spectrum and the same angular correlations. The density distribution in the Dalitz circle[7] should be invariant under rotations by 120° (besides being by definition symmetric about the vertical axis). Insofar as the experimental data presently available indicate a more or less isotropic distribution,[8] our conclusion is not contradicted by the observations, but with improved statistics a more sensitive test will become possible.

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[5] Introduce field operators: ψ_ν ($\nu=1\cdots4$) for the pseudovector τ, and φ_α ($\alpha=1,2,3=$isotopic spin index) for the π. A simple interaction yielding a final state $I=1$ would be $\int dx\psi_\nu\partial_\nu(\varphi_1-i\varphi_2)\times\Sigma_\alpha\varphi_\alpha{}^2$, but this is not symmetric in the 3 pions; actually $\tau/\tau'=1$ in this case. Straight symmetrization gives zero because $\partial_\nu\psi_\nu=0$.
[6] The corresponding interactions are:

$$0^-:\quad \int dx\psi(\varphi_1-i\varphi_2)\,\Sigma_\alpha\varphi_\alpha{}^2,$$

$$3^+:\quad \int dx\psi_{\lambda\mu\nu}\partial_\lambda(\varphi_1-i\varphi_2)\,\Sigma_\alpha\partial_\mu\varphi_\alpha\partial_\nu\varphi_\alpha$$

(ψ symmetric in all 3 indices).
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Method for Determining Spins of Hyperons*

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THE purpose of this note is to point out an experimental method which may be used to determine the spins of the Λ^0 and Σ hyperons. It consists in studying angular correlation effects in the decay of hyperons produced in the capture of negative K-mesons by protons. The capture reactions are

$$K^-+p\rightarrow\Sigma^\pm+\pi^\pm,$$
$$K^-+p\rightarrow\Lambda^0+\pi^0;$$

and the angle in question, denoted by θ, is the angle in the hyperon rest frame between the line of flight of the decay products and the line of flight of the hyperon.

Table I. Angular correlation function.

J	$f_J(\theta)$
3/2	$1+3\cos^2\theta$
5/2	$1-2\cos^2\theta+5\cos^4\theta$
7/2	$1+5\cos^2\theta-(55/3)\cos^4\theta+(175/9)\cos^6\theta$

Although the present remarks may be generalized to more complicated cases, we consider in detail here only the simplest possibility: namely, that the spin of the K-meson is zero (there is some evidence that this is so for the τ meson[1]). We also assume that the K-meson is captured from an S-state, as in the analogous case of capture of π mesons by protons.[2] The angular correlation function $f_J(\theta)$ (probability per unit solid angle) is then uniquely determined by the hyperon spin, denoted by J.

The theoretical analysis involved here is identical with that which is used to study angular correlation effects in nuclear reactions which proceed through a single compound-nucleus state of definite angular momentum and parity. Similar applications to the new unstable particles have been discussed by Adair,[3] who considers angular correlation effects in the process $\pi^-+p\rightarrow Y+K$; and Gatto,[4] who considers such effects in the chain of decay processes: $\Xi^-\rightarrow\Lambda^0+\pi^-$; $\Lambda^0\rightarrow p+\pi^-$.

Let $\psi_{\frac{1}{2}}{}^{M'}$ be the wave function of the system hyperon plus pion, where the index $\frac{1}{2}$ denotes the total angular momentum and $M'=\pm\frac{1}{2}$ is the z-component of angular momentum. We can decompose this into products of eigenfunctions representing the orbital angular momentum state of the reaction products and the spin state of the hyperon, $\psi_J{}^M$:

$$\psi_{\frac{1}{2}}{}^{M'}=\sum_{m+M=M'}A_LC(J,L,\tfrac{1}{2};M,m)Y_L{}^m\psi_J{}^M.\qquad(1)$$

The quantities C are the usual Clebsch-Gordan coefficients; and A_L is the amplitude of the orbital state Y_L. Note that no sum over L is involved in the above expression. This is because in the example under consideration (K-meson of spin zero) the orbital angular momentum L is fixed by the relative parities of the particles involved in the capture reaction; depending on the parities, L may have either of the two values $L=J\pm\frac{1}{2}$, but not both. For K-mesons of spin greater than zero, more than one orbital state is possible and one must then know the relative values of the ampli-